3 CLEANER PRODUCTION OPPORTUNITIES

Fish processing typically consumes large quantities of water and energy and discharges significant quantities of organic material, both as effluent and as solid waste. However, there is very little use of hazardous substances. For this reason, Cleaner Production opportunities described in this guide focus on reducing the consumption of resources, increasing yields and reducing the volume and organic load of effluent discharges.

Although many processes in the industry can be automated, it is difficult to automate the handling of fish and fillets because of the slippery surfaces, variations in size and delicate nature of the product. Therefore, operators generally direct fish and fish products manually through the process. This means that operator practices have a significant impact on the plant performance, particularly in small-scale, less automated operations. As a result, many of the Cleaner Production opportunities described in this section relate to good housekeeping practices, work procedures, maintenance regimes and resource handling.

Section 3.1 provides examples of general Cleaner Production opportunities that apply across the entire process, whereas Sections 3.2 onwards present opportunities that relate specifically to individual unit operations within the process. For each unit operation, a detailed process description is provided along with Cleaner Production opportunities specific to that activity. Where available, quantitative data for the inputs and outputs applicable to each unit operation are also provided.

3.1 General

Many food processors who undertake Cleaner Production projects find that significant environmental improvement and cost savings can be derived from simple modification to housekeeping procedures and maintenance programs. Table 3–1 is a checklists of some of these ways. They are generic ideas that apply to the process as a whole.

Table 3–1 Checklist of general housekeeping ideas [1]

- Keep work areas tidy and uncluttered to avoid accidents.
- Maintain good inventory control of raw ingredients.
- Ensure that employees are aware of the environmental aspects of the company’s operations and their personal responsibilities.
- Train staff in good cleaning practices.
- Schedule maintenance activities on a regular basis to avoid inefficiencies and breakdowns.
- Optimise and standardise equipment settings for each shift.
- Identify and mark all valves and equipment settings to reduce the risk that they will be set incorrectly by inexperienced staff.
- Improve start-up and shut-down procedures.
- Segregate waste for reuse and recycling.
- Install drip pans or trays to collect drips and spills.

[1] UNEP Cleaner Production Working Group for the Food Industry, 1999

3.1.1 Water consumption

Water is used extensively in fish processing, so water saving measures are very common Cleaner Production opportunities in this industry. Water is used not only for fish cleaning, but also to flush offal and blood from equipment and floors, and to flume the offal to floor drains and collection sumps. Automated processing equipment generally has permanently installed water sprays to keep the equipment clean and to flush offal away.

The first step in reducing water consumption is to analyse water use patterns carefully, by installing water meters and regularly recording water consumption. Water consumption data should be collected during production hours, especially during periods of cleaning. Some data should also be collected outside normal working hours to identify leaks and other areas of unnecessary wastage. Water consumption data should be presented and discussed at management meetings to formulate strategies for improved water efficiency. Discussion could include whether water needs to be used at all in some processes; for example, could transport systems avoid the use of water?

The next step is to undertake a survey of all process area and ancillary operations to identify wasteful practices. Examples might be hoses left running when not in use, water sprays on process lines operating when no processing is taking place, the continual running of water used for thawing, and so on. Installing automatic shut-off equipment, such as sensors, solenoid valves, timers and thermostats, could prevent such wasteful practices. Automatic control of water use is preferable to relying on operators to manually turn water off.

Once wasteful practices have been addressed, water use for essential process functions can be investigated. It can be difficult to establish the minimum consumption rate necessary to maintain process operations and food hygiene standards. The optimum rate can be determined only by investigating each process in detail and undertaking trials. Such investigations should be carried out collaboratively by production managers, food quality and safety representatives and operations staff. When an optimum usage rate been agreed upon, measures should be taken to set the supply at the specified rate and remove manual control.

Once water use for essential operations has been optimised, water reuse can be considered. Wastewaters that are only slightly contaminated could be used in other areas. For example, wastewater from fish thawing could be used for offal fluming or for initial cleaning steps in dirty areas. Wastewater reuse should not compromise product quality and hygiene, and reuse systems should be carefully installed so that reused wastewater lines cannot be mistaken for fresh water lines, and each case should be approved by the food safety officer.

Table 3–2 Checklist of water saving ideas [1]

- Use offal transport systems that avoid or minimise the use of water.
- Install fixtures that restrict or control the flow of water for manual cleaning processes.
- Use high pressures rather than high volumes for cleaning surfaces.
- Reuse relatively clean wastewaters for other applications; for example, thawing wastewaters could be used for offal fluming or for initial cleaning steps in dirty areas.
- Use compressed air instead of water where appropriate.
- Install meters on high use equipment to monitor consumption.
- Use closed circuit cooling systems.
- Pre-soak floors and equipment to loosen dirt before the final clean.
- Recirculate water used in non-critical applications.
- Report and fix leaks promptly.

[1] UNEP Cleaner Production Working Group for the Food Industry, 1999.

3.1.2 Effluent

Cleaner Production efforts in relation to effluent generation should focus on reducing the pollutant load of the effluent. The volume of effluent generated is also an important issue. However this aspect is linked closely to water consumption, therefore efforts to reduce water consumption will also result in reduced effluent generation. Opportunities for reducing water consumption are discussed in Section 3.1.1.

Opportunities for reducing the pollutant load of fish processing effluent principally focus on avoiding the loss of raw materials and products to the effluent stream. This means capturing materials before they enter drains and using dry cleaning methods. Therefore, improvements to cleaning practices are an area where the most gains can be made. Table 3–4 contains a checklist of common ideas for reducing effluent loads.

Table 3–3 Checklist of ideas for reducing effluent loads [1]

- Sweep up solid materials for use as a by-product, instead of washing them down the drain.
- Clean dressed fish with vacuum hoses and collect the blood and offal in an offal hopper rather than the effluent system.
- Fit drains with screens and/or traps to prevent solid materials from entering the effluent system.
- Use dry cleaning techniques where possible, by scraping equipment before cleaning, pre-cleaning with air guns and cleaning floor spills with squeegees.

[1] UNEP Cleaner Production Working Group for the Food Industry, 1999.

3.1.3 Energy

Fish processing uses electricity to operate machinery, lighting, air compressors and cold storage facilities. Thermal energy in the form of steam and hot water is used for cooking, cleaning and sanitising.

Energy is often an area where substantial savings can be made almost immediately with no capital investment. Significant reductions in energy consumption are possible through improved housekeeping and optimisation of existing processes, and additional savings can be made through the use of more energy-efficient equipment and heat recovery systems.

In addition to reducing a plant's demand for energy, there are opportunities for using more environmentally benign sources of energy. Opportunities include replacing fuel oil or coal with cleaner fuels, such as natural gas, purchasing electricity produced from renewable sources, or co-generation of electricity and heat on site. For some plants it may also be feasible to recover methane from the anaerobic digestion of high-strength effluent streams to supplement fuel supplies.

Table 3–4 Checklist of energy saving ideas [1]

- Implement switch-off programs and install sensors to turn off or power down lights and equipment when not in use;
- Improve insulation on heating or cooling systems and pipework.;
- Favour more efficient equipment;
- Improve maintenance to optimise energy efficiency of equipment;
- Maintain optimal combustion efficiencies on steam and hot water boilers;
- Eliminate steam leaks;
- Capture low-grade energy to use elsewhere in the operation.

[1] UNEP Cleaner Production Working Group for the Food Industry, 1999.

3.1.4 By-products

An important waste reduction strategy for the industry is the recovery of marketable by-products from fish wastes. Surimi and flaked fish are good examples of products created from previously undervalued fish parts.

Chitin and chitosan, chemicals extracted from crab and shrimp shells, produce chitinous polymers similar to cellulose. Chitosan has been used for the manufacture of animal meal products and for various medical applications. Potential uses for fish residue and offal are also being examined in some parts of the world. Hydrolysed fish wastes can be used for fish or pig meal, as well as fertiliser components.

To allow for the efficient collection and utilisation of these by-products, transportation of fish residues and offal without the use of water is very important. Filtering conveyors can be installed under process equipment, or vacuum systems can be used to transport offal directly to storage containers. In plants dominated by manual operations, bins can be provided in suitable locations to collect the offal instead of letting it drop to the floor.

Filleting

3.1.5 Thawing

Process description

In order to be able to produce all year round or to receive sufficient amounts of raw material, some operations use frozen fish. Thawing of frozen fish can be carried out in a number of ways, either in a batch process or using continuous thawing conveyors. The most common method is to immerse the frozen blocks of fish in water.

Inputs and outputs

Figure 3–1 is a flow diagram showing the inputs and outputs for this process and Table 3–5 provides data for the key inputs and outputs.

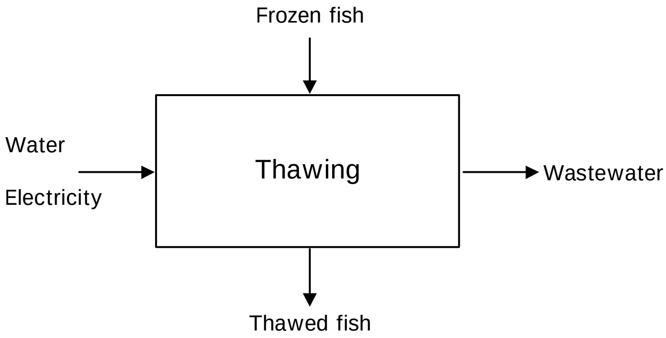

Figure 3–1 Inputs and outputs for the thawing of frozen fish

Table 3–5 Input and output data for thawing of frozen fish

Inputs		**Outputs**	
Frozen fish	1000 kg[1]	Thawed fish	950–990 kg[1]
Water	5 m^3	Wastewater	5 m^3
		COD	1–7 kg

[1] The weight loss between frozen and thawed fish is attributed to water loss from the fish which occurs as a result of thawing.

Environmental issues

Large amounts of water are used in the thawing process, and can account for around 50% of the total water use when frozen fish are used for filleting. However the amount used depends on the thawing procedure used.

While the fish is thawing in water, the thaw water becomes contaminated with organic material such as intestinal remains, scales and slime. The extent of contamination depends on how well cleaning and gutting were carried out on board the fishing vessels. It can also depend to some extent on the fish species. For example, species such as haddock will contaminate the water with slime and scales more than other species.

Cleaner Production opportunities

Instead of the traditional thawing method, the so-called *Lorenzo method* can be used. In this method, thaw water is heated to 30–35°C to facilitate thawing and the water is agitated with an air sparge, giving a better contact between fish and water. The capital investment is around

US$50,000 and energy is needed for heating the water. However, water consumption is reduced by about 40% to about 3 m^3/t RM.

The *moist air method* utilises a warm, humid air stream and consumes virtually no water. It is therefore a preferred method in terms of water consumption. However, an energy input of about 70 kW.h/t RM is required to heat the moist air. This method has become popular, because less raw material is lost during thawing and the quality of the thawed product is often better. The capital investment for a system with a capacity of 6.5 t/h is around US$230,000. In this case all thawing water, approximately 5 m^3/t RM, will be saved.

3.1.6 De-icing, washing and grading

Process description

The processes described in this section relate to the preparation of fish for filleting. Boxes of fish containing ice and water are emptied into a de-icer tank, in which the contents are stirred to make the fish sink to the bottom and the ice float to the surface. The ice is then skimmed off the surface, assisted by an overflow system.

In a well-functioning operation, fish are graded according to size to optimise yield in subsequent processing steps. An automated grading system operates by passing the fish down an inclined plane, sorting the fish by size along the way.

Inputs and outputs

Figure 3–2 is a flow diagram showing the inputs and outputs for this process and Tables 3–6 and 3–7 provide data for the key inputs and outputs for de-icing and washing fish and for grading fish respectively.

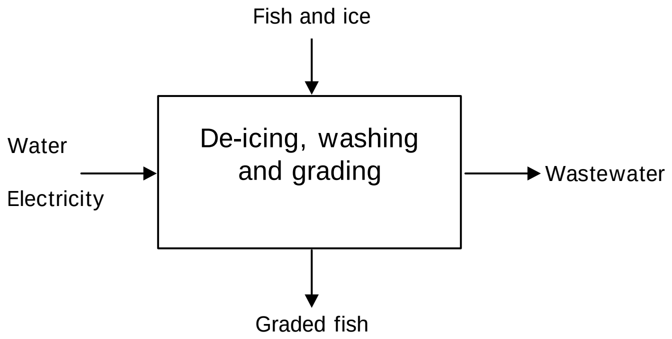

Figure 3–2 Inputs and outputs for de-icing, washing and grading

Table 3–6 Input and output data for de-icing and washing

Inputs		Outputs	
Ice and fish	1000 kg	Fish	980–1000 kg
Water	1 m^3	Wastewater	1 m^3
Electricity	0.8–1.2 kW.h	COD	0.7–4.9 kg
		Solid waste	0–20 kg

Table 3–7 Input and output data for grading fish

Inputs		Outputs	
Fish	1000 kg	Graded fish	980–1000 kg
Water	0.3–0.4 m^3	Wastewater	0.3–0.4 m^3
Electricity	0.1–0.3 kW.h	COD	0.4–1.7 kg
		Solid waste	0–20 kg

Environmental issues

Water is supplied to the de-icer tank to compensate for the water that overflows from the tank. The rate of water consumption is about 1 m^3 per tonne of fish, but depends on the capacity of the machine. Water is also used at the grading equipment to keep the fish lubricated so that they slide down the grading incline. The rate of water consumption for this is about 0.3–0.4 m^3 per tonne of fish.

The wastewater discharged from these processes contains minor amounts of organic matter, the quantity of which depends on fish quality.

Cleaner Production opportunities

Reducing the amount of water that overflows from the de-icing tanks can save water. When the de-icer tanks are topped up, the supply should be shut off when the level is approximately 100 mm below the overflow, to accommodate the water level rise that occurs when the ice melts. The water can be shut off manually, but a level-actuated solenoid valve on the fresh water supply is a more effective means of controlling water use. Using an automated shut-off system could save about 1 m^3/t RM, with an initial investment of about US$800.

The ice/water mixture overflowing from the de-icer tanks may be used for other processes that require chilled water (e.g. scaling operations). The investment for the equipment to do this could be between US$1000 and US$2000. As well as water savings, there will also be some energy savings.

Water consumption at the grading equipment will depend on the quality of the raw fish. Fish of low quality will increase the need for water, to keep the equipment clean. Reductions in water use can be achieved by adjusting consumption rates to meet the actual need. If adjustable valves are installed, the operator can adjust the flow or change to spray nozzles with a lower water consumption. Water savings can be in the order of 50–65%, thus saving about 0.2 m^3/t RM, against an initial investment of about US$200–400.

Case Study 3–1: Water savings on de-icer

In a hake filleting plant, it was calculated that water use at the de-icing equipment could be reduced by 80%. The company has improved housekeeping and installed a level-actuated switch to control water feed. Water savings have been 120 m^3 per day, resulting in a payback time of less than one week.

3.1.7 Scaling

Process description

Scaling equipment consists a perforated, rotating drum, onto which water is applied to flush scales away. If the fillets are to be skinned, it is normally not necessary to scale the fish.

Inputs and outputs

Figure 3–3 is a flow diagram showing the inputs and outputs from this process and Table 3–8 provides data for the key inputs and outputs.

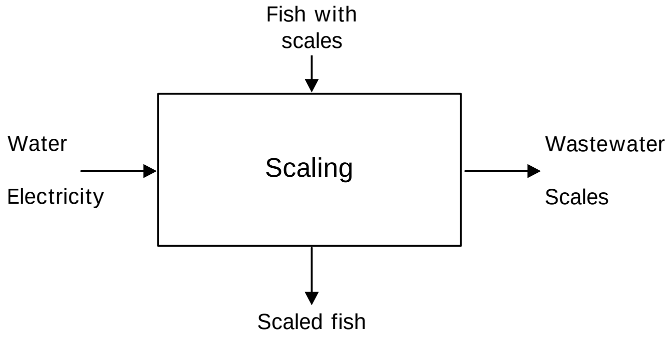

Figure 3–3 Inputs and outputs for scaling

Table 3–8 Input and output data for the scaling of white fish

Inputs		Outputs	
Fish with scales	1000 kg	Scaled fish	960–980 kg
Water	10–15 m^3 [1]	Wastewater	10–15 m^3
Electricity	0.1–0.3 kW.h	Scales	20–40 kg

[1] Water consumed by scaling equipment is typically around 20–30 m^3 per hour. This equates to 10–15 m^3 per tonne of fish, based on 2 tonnes of fish per hour.

Environmental issues

Like most steps in the process, scaling contributes to overall water consumption and to the organic load of the effluent stream. In addition, the scaling process can influence material losses in subsequent processing steps, due to the harsh nature of this treatment.

Cleaner Production opportunities

The necessity for scaling should be assessed on a fish-by-fish basis, bearing in mind that scaling is not required if the fish is to be skinned. If scaling can be avoided, water savings will be in the order of 10–15 m^3 per tonne fish, with no need for capital investment.

Wastewater from the scaling operation can be filtered and recirculated, but the fish must be rinsed with fresh water before leaving the scaler to remove any loose scales and contaminated water. Recirculated water can be chilled with ice from the de-icing operation. The capital investments required for this are very low, while water savings can be about 70%. Water quality must be checked regularly.

Alternatively, proper adjustment of the scaler operation can reduce the quantity of water used in the scaler by 30–60%, with no capital investment. Adjustments should be based on assessments of the performance of the scaler, by weighing the amount of scales and undertaking visual examinations.

Case Study 3–2: Water reduction through optimised scaling

In a hake filleting plant, the water used in the scaling process was 30 m^3/h. Water was supplied by three jets, spraying water on the fish and the drum from three directions. The performance of the scaler was evaluated by weighing the quantities of scales removed from a batch of fish and by visual examination of the scaled fish. It was found that one water jet performed no useful function and the spray rate from the other two jets could be significantly reduced without reducing the efficiency of the scaling process. Overall, water consumption was reduced by one-third, to 20 m^3/h. The process is now being examined further to identify additional potential savings. It is anticipated that another 5–10 m^3/h can be saved.

3.1.8 De-heading

Process description

In automated processes, fish are fed into the de-heading machine from a buffer storage supply. Water is used in the machine to lubricate the fish as they pass through the machine, to clean the rotating knives and to make sure that the heads are ejected from the machine. The removed heads are either collected in storage containers or transported away from the process in a water flume or by conveyor. In manual processes, the head is cut off with a knife and dropped in a container.

Inputs and outputs

Figure 3–4 is a flow diagram showing the inputs and outputs from this process and Table 3–9 provides data for the key inputs and outputs.

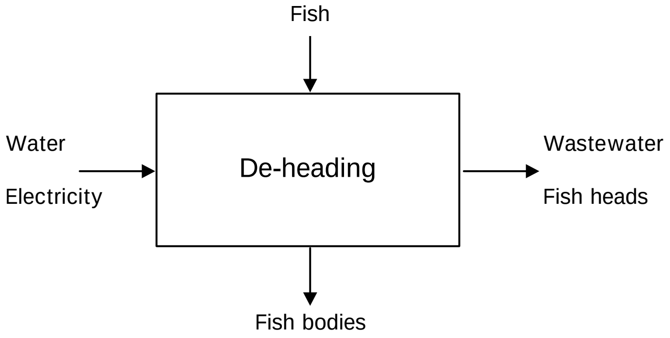

Figure 3–4 Inputs and outputs for de-heading of fish

Table 3–9 Input and output data for the de-heading of white fish

Inputs		**Outputs**	
Whole fish	1000 kg	Fish bodies	680–730 kg
Water	~ 1 m^3	Wastewater	~ 1 m^3
Electricity	0.3–0.8 kW.h	COD	2–4 kg
		Waste (heads and debris)	270–320 kg

Environmental issues

A typical water consumption rate for de-heading processes is approximately 1 m^3 per tonne of fish, but it can be lower for modern machinery. Water is also used to transport offal using flumes, and this requires a vigorous flow. The organic loading of wastewater generated from the de-heading process is relatively high, due to contamination with blood and flesh pieces.

Cleaner Production opportunities

As mentioned previously, one function of the water in the de-heading machine is to ensure that the removed heads are discharged from the machine and do not pile up on the slide. However, modifying the slide so that it is sufficiently steep will eliminate the need for water. Heads may still accumulate on the horizontal section immediately behind the knives, in which case the operator will have to push the heads out of the machine manually. Water may still be needed for intermittent cleaning, but water savings of about 1 m^3 of water per tonne fish can be achieved with little capital investment.

3.1.9 Cutting of fillets

Process description

The filleting process for white fish differs slightly from that for oily fish. White fish have generally been gutted and cleaned beforehand, so that the filleting processes involves only the removal of the fillet flesh.

Oily fish, on the other hand, have usually not been gutted, cleaned or de-headed prior to this step, so the filleting process involves the gutting and de-heading of the fish as well as the removal of the fillets.

For white fish species, the de-headed fish are manually placed on the filleting machine and rotating knives cut the fillets from the bone and cut off the collar bones. From there, the two fillets are conveyed skin-side down to the skinning machine.

For oily fish, the whole fish is orientated in a forward direction and manoeuvred into position, using water jets, until it is aligned with a stop plate. The head and tail are removed, then the belly flap is cut and the belly cavity cleaned to remove the guts. Two pairs of rotating knives then cut the fillets from the bone. The fillets continue to the skinner.

Inputs and outputs

Figures 3–5 and 3–6 are flow diagrams showing the inputs and outputs from the filleting of white and oily fish respectively. Tables 3–10 and 3–11 provide data for the key inputs and outputs for white and oily fish respectively.

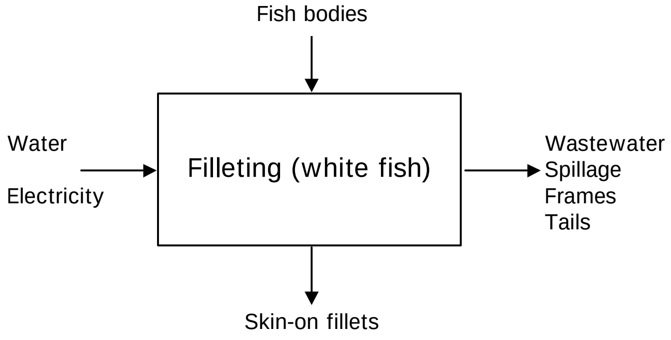

Figure 3–5 Inputs and outputs for filleting white fish

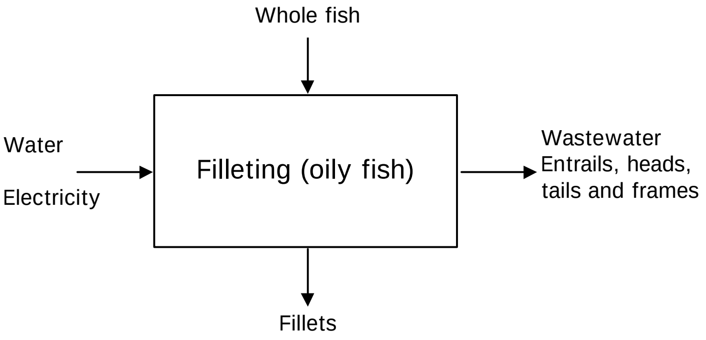

Figure 3–6 Inputs and outputs for filleting oily fish

Table 3–10 Input and output data for filleting of de-headed white fish

Inputs		Outputs	
Fish bodies	1000 kg	Skin-on fillets	700–810 kg
Water	1–3 m^3	Wastewater	1–3 m^3
Electricity	1.8 kW.h	COD	4–12 kg
		Waste (frames and offcuts)	200–300 kg

Table 3–11 Input and output data for filleting of un-gutted oily fish

Inputs		Outputs	
Whole fish	1000 kg	Fillets	550 kg
Water	1–2 m^3	Wastewater	1–2 m^3
Electricity	0.7–2.2 kW.h	COD	7–15 kg
		Waste (entrails, tails, heads and frames)	~ 440 kg

Environmental issues

The filleting of fish, when done either by hand or by machine, consumes large amounts of water for rinsing the fish and for cleaning knives and equipment. Often continuous rinsing is required to keep work areas free of fish remains. For the filleting of un-gutted oily fish, water is also used for rinsing the belly cavity and for manoeuvring the fish into position before the head is cut off.

Water used for cleaning and rinsing subsequently becomes wastewater, carrying with it fish scraps and entrails. Solids that fall to the floor are also washed to the nearest drain with water.

The entrails and offal from the gutting of oily fish contain high levels of oil and easily soluble matter, and wastewater generated from the filleting of oily fish therefore has a high COD, in the range of 3000–60,000 mg/L. In comparison the COD for wastewater generated from the filleting of white fish is lower, typically 2000–6000 mg/L.

Cleaner Production opportunities

There are various ways of reducing the amount of water consumed in the filleting process. Spray nozzles can be replaced with smaller or more efficient ones, and water pressure can be reduced Sprays can be operated intermittently (e.g. 3 seconds on, 3 seconds off), instead of constantly. In some places, water use can be eliminated by using manual scrapers for removing the build-up of solids on the filleting machines. Solenoid valves should be used to stop water flow when the machines are not in operation.

For oily fish filleting, the water jets that align the fish for removal of the heads can be replaced by a rotating brush. The capital investments for these water saving ideas are all quite low and the water used for filleting can be reduced by 50–90%.

For the highest possible product yields, knives must be correctly aligned and kept sharp. This can be achieved by appropriate operator training, for which capital investment is low.

Stainless steel catch trays placed around the filleting machines can capture solid material that falls from the machines. When filleting is done by hand, most solid wastes end up on the floor and spills occur when offal is transferred to storage containers or onto conveyor belts. Chutes can be installed to capture offal from the filleting tables. These measures can considerably reduce the organic matter discharged in the effluent stream when work areas and floors are cleaned.

The fish frames that remain after filleting can be sold as secondary product to the fish meal industry.

The entrails from the filleting of oily fish can be removed by a vacuum system that sucks and transports the viscera away from the filleting machine. This reduces the consumption of water in this area by about 70%, a reduction of approximately 1.3 m^3 per tonne of fish. It can also reduce the COD of the wastewater stream by about the same proportion, which is a reduction of approximately 4–8 kg per tonne of fish. However the capital investment for such systems is high and energy consumption is high.

Case Study 3–3: Water savings on a filleting machine

A filleting plant installed nozzles on three filleting machines and a simple switch that stopped water when the operator was not at the machine. The investment was only about US$100 and saved 34 m^3 of water was saved per day. The resulting payback period was less than a week.

Case Study 3–4: Optimisation of filleting machine

A Danish company that processes 6000 tonnes of herring every year, on four filleting machines, has introduced a dry gutting process. The water supply to the entrails-cutting wheel was disconnected, and instead the entrails and guts are transported to a container on a conveyor. The investment for four filleting machines was US$35,000. The collected entrails are sold and the water consumption is reduced, saving the company US$7400 every year (after depreciation of the equipment). The environmental benefit is a reduction of organic content in the wastewater in the range of 35%.

3.1.10 Skinning

Process description

In manual processing, the fillets are skinned with a knife at the same work station as the filleting. For automated operations, white fish are skinned by pulling the fillet over a knife, and oily fish are skinned by pulling the fillet over a freezing drum. Water is used for cleaning and lubrication of the machinery.

Inputs and outputs

Figure 3–7 is a flow diagram showing the inputs and outputs from this process. Tables 3–12 and 3–13 provide data for the key inputs and outputs for white and oily fish respectively.

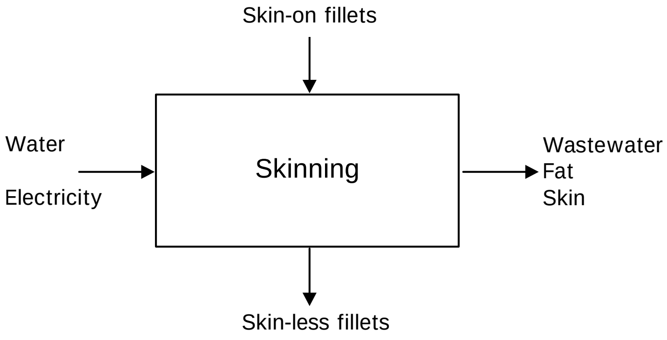

Figure 3–7 Inputs and outputs for skinning

Table 3–12 Input and output data for skinning white fish

Inputs		Outputs	
Skin-on fillets	1000 kg	Skinless fillets	930–950 kg
Water	0.2–0.6 m^3	Wastewater	0.2–0.6 m^3
Electricity	0.4–0.9 kW.h	COD	1.7–5.0 kg
		Waste (skin)	~ 40 kg

Table 3–13 Input and output data for skinning oily fish

Inputs		Outputs	
Skin-on fillets	1000 kg	Skinless fillets	930–950 kg
Water	0.2–0.9 m^3	Wastewater	0.2–0.9 m^3
Electricity	0.2–0.4 kW.h	COD	3–5 kg
		Waste (skin)	~ 40 kg

Environmental issues

The skinning of white fish can contribute significantly to the pollution load of effluent generated from the plant, especially if the quality of the fish is poor. Soft fillets tend to get caught in the skinning equipment and are torn to pieces, reducing yield and increasing waste.

The skinning of oily fish results in the release of large quantities of fish oil to the wastewater stream. The oil comes from the layer of oil just under the skin of the fish and is released during skinning. It is washed away with the water that is constantly applied to the skinning drum to keep it clean. The skinning process contributes about one-third of the overall COD load in the effluent stream.

Cleaner Production opportunities

An important way of reducing the loss of flesh during the skinning operation is to improve the quality of the fish received into the plant, through proper handling from the moment the fish are caught. Secondly, maintenance of machinery is important to ensure that the skinning process is as efficient as possible.

To save water, the number of spray nozzles on the equipment or the size of the nozzles can be reduced. These measures can reduce water consumption by 75%. Additional savings can result by operating the sprays intermittently instead of constantly. The organic load (COD) of the resulting wastewater can also be reduced by 5–10%. For all of the above options, the capital investment is low.

A vacuum system can be used as an alternative to water for removing the skin, fat and flesh pieces from the skinner drum. This will almost eliminate the water consumption from the process. However the high capital cost of such equipment must be considered.

A vacuum system can be mounted on skinning units for oily fish to remove all skin, oil and flesh pieces from the skinner drum. With the exception of a single, small spray nozzle, which sprays water into the drum to keep it moist, water consumption is virtually eliminated. A typical investment for four filleting machines is about US$88,000. The benefits are a reduction in water consumption of about 95%, as well as a reduction in the COD of the wastewater. Across the whole filleting process, total water consumption can be reduced by 17%. This also results in a reduction in overall COD load from filleting and skinning.

3.1.11 Trimming and cutting

Process description

Trimming and cutting are undertaken to remove bones and defects from the fillets and to portion the fillets into smaller pieces. These are often a manual processes, although they can be automated. Any remaining bones are removed, and fins, blood, discoloration and belly membrane materials are cut away. The offcuts from these processes are normally used in the production of fish mince. The trimmed fillets are transported by conveyor belt or in boxes.

Inputs and outputs

Figure 3–8 is a flow diagram showing the inputs and outputs from the trimming and cutting process. Table 3–14 provides data for the key inputs and outputs.

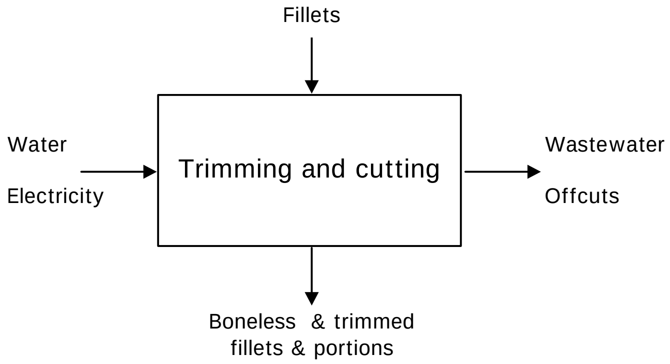

Figure 3–8 Inputs and outputs for trimming and cutting

Table 3–14 Input and output data for trimming and cutting white fish

Inputs		**Outputs**	
Fillets	1000 kg	Boneless fillets	660–760 kg
Water	0.1 m^3	Wastewater	0.1 m^3
Electricity	0.3–3 kW.h	Waste (bones and cut-off)	240–340 kg

Environmental issues

Water is used for cleaning the fillets and cutting plates, for rinsing the conveyor and boxes, and for cleaning the workplace in general. In some operations, a constant stream of water is used to clean the cutting plates, conveyors and knives. In these situations, water consumption will be much higher than indicated in the above table.

As in many of the other processing areas, losses of materials from the trimming and cutting lines end up on the floor, and if work areas are not well designed, they can be washed to the drain, contributing to the organic load of the effluent stream.

Cleaner Production opportunities

Spray guns can be installed at work areas for occasional cleaning tasks and automatic spray systems can be fitted with solenoid valves so that they operate intermittently. The capital expenditure for these modifications are low and water consumption can be reduced by 50%.

3.1.12 Packaging, freezing and storage

Process description

The fillets are packed in cartons and typically frozen in horizontal plate freezers. Once frozen, the cartons are placed in cold storage until required for distribution and retail.

Inputs and outputs

Figure 3–9 is a flow diagram showing the inputs and outputs from this process. Tables 3–15 and 3–16 provide data for the key inputs and outputs.

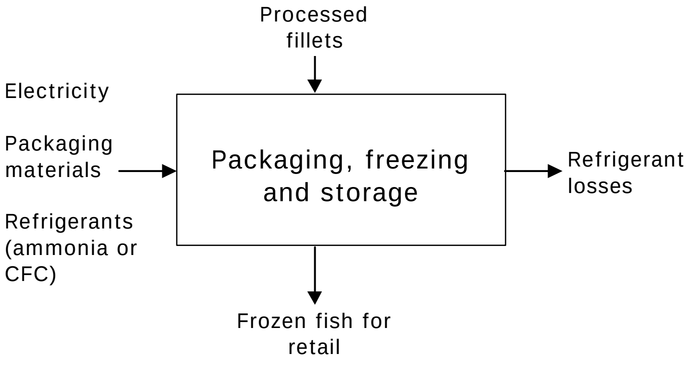

Figure 3–9 Inputs and outputs for packaging, freezing and storage

Table 3–15 Input and output data for packaging of fillets

Inputs		Outputs	
Processed fillets	1000 kg	Fish for retail	~ 1,000 kg
Electricity	5–7.5 kW.h		
Packaging material	NA		

Table 3–16 Input and output data for freezing and storage

Inputs		Outputs	
Packed fish	1000 kg	Frozen fish	~ 1000 kg
Water (for ice)	0.2 m^3		
Electricity	10–14 kW.h		
Additives	various		

Environmental issues

Freezing and refrigeration consume large quantities of energy, and inefficient equipment can result in emission of refrigerant gases, such as ammonia or CFC, depending on which system is used.

Cleaner Production opportunities

The following is a list of possible ways to reduce energy consumption:

- Ensure that the capacity of the cold storage closely matches the production capacity of the operation. It may be convenient to have additional storage capacity, but the extra energy costs of cooling unused capacity may be considerable. This is best addressed during the planning stage of a new development or during refurbishment or upgrades.
- Ensure that cold storage rooms are well insulated and fitted with self-closing doors with tight seals.
- Strictly enforce procedures that ensure cold storage units are defrosted as necessary. If defrosting occurs either too frequently or too infrequently, energy consumption will increase. Such maintenance measures cost little, but require changes in habits.
- Ensure that refrigeration systems are properly maintained. An ongoing maintenance schedule should be established and, whenever leaks or damaged insulation are detected, repairs should be carried out promptly.
- Use non-CFC refrigeration systems, such as those that use ammonia. It can be costly to change refrigeration systems, but it has become necessary due to the Montreal Protocol related to the use of ozone-depleting substances.

3.1.13 Collection and transport of offal

Process description

The conventional method for collecting and removing offal is to allow it to collect in drains adjacent to work areas and then flume it away with water. Generally, water from the filleting and de-heading machines is used for this purpose. It is usually necessary, however, to add some fresh water to transport the solid offal away effectively.

Environmental issues

Fluming of offal is responsible for a considerable proportion of the effluent generated from fish processing plants. During transportation of the offal in the water flume, organic matter is dissolved in the water stream, contributing to high levels of COD and nutrients.

Cleaner Production opportunities

Instead of transporting offal via drains and water flumes, a conveyor with a mesh size of about 1 mm can be installed underneath each filleting line. As well as transporting the offal away, the conveyor acts as a filter.

Wastewaters flowing away from machines and workstations are filtered through the conveyor belt, while the solid offal is retained on the belt, to be transported to the offal collection area. Only particles smaller than 1 mm will pass through the filter, so fish offal is quickly separated from the water stream and contamination of water is limited to small solid particles. The filter conveyor is fitted with a spray system to maintain its filtration capacity and it must also be cleaned thoroughly once a day. In most cases, the filter conveyor can be set up to collect offal from the de-heading, filleting and skinning machines.

In the white fish industry, it is estimated that filter conveyors decrease the total COD of the load from a facility by 5–15% if the factory has a central filter conveyor, or 15–25% if the factory has a rotary sieve. In the herring filleting industry, the reductions in COD that can be achieved are as high as 30–50%, due to the greater pollution that is normally generated from gutted oily fish.

The water used for transport of offal can be filtered and recirculated. This will save water, but there are also drawbacks. When crudely filtered process water is pumped, the oil becomes emulsified in the water. This may cause an increase of consumption of chemicals for flotation or sedimentation at the wastewater treatment plant.

The collection of offal without the use of water will result in a larger quantity of offal being collected, and this will provide increased revenue from the sale of the offal to fish meal plants. The material for processing may also command a higher price, due to its reduced water content.

As a rule of thumb, at least 0.3–0.5% of the raw material weight can be collected if filtering conveyors are installed, but this figure can be as high as 1%, depending on the performance of the plant.

To install a filter conveyor 6m in length under the heading, filleting and skinning machine, the capital expenditure will be approximately as follows:

Filter conveyor with spray system	US$6300
Installation	US$1800
Miscellaneous components	US$400
Total	**US$8500**

These figures do not include the costs for a central conveyor that collects the offal from the filter conveyors. Payback times of 2–3 years have been reported however this depends on the performance of the plant and the prices obtained from the sale of the offal.

For smaller oily fish species, such as herring, the offal can be removed by a vacuum system. After the head is cut off, a vacuum is used to suck out the guts, which are passed directly to collection containers.

The removal of offal from white fish by vacuum has also been investigated. This resulted in about 70% reduction in COD of the discharged wastewater. The reduction in water use was similar, and it was estimated that up to 5% more offal was collected. This can be sold for fish meal production and thus generate an income. The system is being used only at the test plant and more experience is needed.

Case Study 3–5: Vacuum removal of offal

A large herring filleting plant has developed and installed new equipment to vacuum-remove offal from the de-headed herrings. The equipment consists of vacuum pumps, pipes and a cyclone separator. For ten filleting machines the total investment was US$80,000. Despite increased income from sales of offal and reduced costs for water, the additional annual costs are US$3150, including depreciation of the equipment. However, the water consumption has been reduced considerably, as well as the organic content of the wastewater.

3.2 Canning

Fish used for canning include sardine, anchovy, pilchard, tuna and mackerel. They are not generally gutted on board the fishing vessels, owing to the large size of the catches.

3.2.1 Unloading of fish

Process description

On the fishing vessel, the fish are held in a tank of water, referred to as the hold. The common method used for unloading the fish from the hold is the ‘wet’ unloading system. The fish, along with water from the hold, are pumped and conveyed to the processing plant along gravity-fed water flumes. The water is allowed to drain away and the fish are weighed and then returned to water-filled holding pits inside the plant.

Inputs and outputs

Figure 3–10 is a flow diagram showing the inputs and outputs from this process. Table 3–17 provides data for the key inputs and outputs.

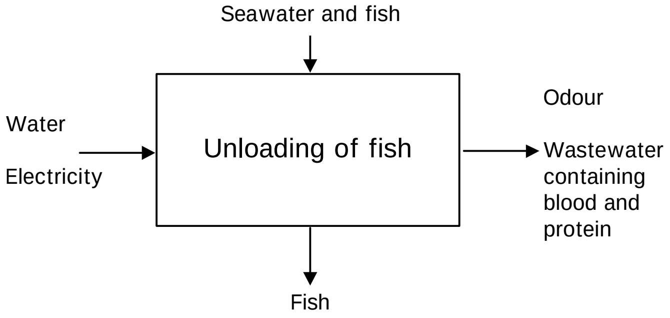

Figure 3-10 Inputs and outputs for unloading fish for canning

Table 3–17 Inputs and outputs for unloading fish for canning

Inputs		Outputs	
Fish and sea water	1000 kg	Fish	980 kg
Water	2–5 m^3	Wastewater	2–5 m^3
Electricity	3 kW.h	COD	27–34 kg

Environmental issues

Sea water is used for transporting and fluming the fish into and around the processing plant, but fresh water is sometimes added to the system to maintain a sufficient water flow.

'Bloodwater' is generated on board the fishing vessels; this term refers to the wastewaters that contain blood from the fish. Depending on fish species and the condition they are in by the time they are unloaded at the processing plant, the bloodwater can represent as much as 20–25% of the total organic load generated from a cannery.

Cleaner Production opportunities

The organic load of the wastewaters generated from the unloading process can be reduced by reducing the contamination of the fish and by chilling the catch. Efficient chilling results in the best-quality fish and reduces losses. Chilling consumes extra energy (approximately 50–60 kW.h/t ice for ice production and 50–70 kW.h for freezing), but the organic load of the wastewater is reduced considerably.

The quantity of fresh water consumed in the unloading process can be reduced by:

- limiting the amount of water added to the pumping and fluming system to that necessary for efficient transport;
- installing solenoid valves that shut off the flow of water when no fish are being unloaded;
- recirculating flume water (although this requires a filtering conveyor system to separate solid matter from the water stream before reuse);
- installing water meters to check that the unloading crew does not use more water than necessary.

Due to the oil and protein content of the bloodwater, it can be utilised for fish meal production, if there is a plant nearby. Alternatively, it can be treated and discharged to sea. Treatment usually involves passing it through a drum sieve and then through a flotation tank (oil interceptor). Using such a system can reduce COD by 6–25%, depending on the retention time. The capital investment required for such a system is of the order of US$50,000.

Treated water from the above mentioned treatment plant can be reused for unloading fish if it is treated with ultraviolet (UV) light or ozone. Samples of the treated water should be regularly tested to ensure that the water is hygienic. The water saving will be 2–5 m^3/t RM, but capital investment required for ultraviolet or ozone treatment is high.

The quality of the treated bloodwater can be further improved before discharge using a centrifuge system, which can reduce suspended matter and solids by 45% (60 kg/t RM). The capital investment required for such systems, however, is high.

Dry unloading systems, which employ vacuum suction to transport the fish, can be used to avoid the use of water. The fish are discharged onto conveyor belts for conveyance to the processing plant. Modern, dry systems can be as effective as wet unloading systems, but some water is still required occasionally to increase the unloading speed.

Mono-pumps can also be used for unloading, with reasonable performance. The capital investment required is about US$100,000 for the pumps and US$500,000 for the storage tanks. Savings in water are 1–2 m^3 of water per tonne RM and the discharge of organic matter is eliminated.

Unloading using containers or conveyors lowered into the storage hold on the fishing vessels is also possible, but access to the hold is often difficult.

3.2.2 Packing into cans

Process description

This step in the process involves separating the edible parts of the fish, cutting the fish into pieces of appropriate size and packing them into cans. From the unloading area, the fish are transported via water flumes to work stations, where they are sorted and placed onto a belt that feeds them to the cutting and packing machines.

Small-sized fish species are canned whole, whereas medium-sized species are first nobbed and then cut into pieces before canning. Nobbing is the process of simultaneously cutting off the head of the fish and removing the entrails. Tails are then cut off, and the rest of the fish is cut into smaller pieces, according to the size of the can. The fish pieces are then automatically placed in the can. Large fish species are first cooked whole, then the edible parts are removed and canned. Skinning is sometimes carried out using warm lye solutions.

Fish offcuts such as the tails, heads and entrails, are transported to the waste collection area or directly to a fish meal plant via chutes, water flumes or conveyor belt. Tails from the medium and large fish species are sometimes collected separately and used for minced products.

Inputs and outputs

Figure 3–11 is a flow diagram showing the inputs and outputs from this process. Tables 3–18, 3–19 and 3–20 provide data for key inputs and outputs.

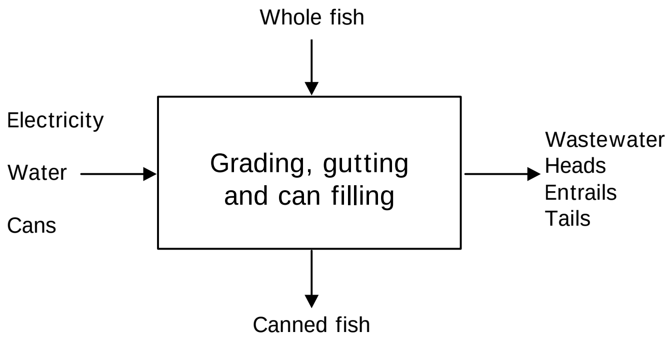

Figure 3–11 Inputs and outputs for grading, gutting and can filling

Table 3–18 Input and output data for grading of fish

Inputs		Outputs	
Whole fish	1000 kg	Graded fish	970–1000 kg
Water	0.2 m^3	Wastewater	0.2 m^3
Electricity	0.15 kW.h	COD	0.35–1.7 kg
		Solid waste	0–30 kg

Table 3–19 Input and output data for nobbing and packing in cans

Inputs		Outputs	
Graded fish	1000 kg	Canned fish	750–760 kg
Water	0.2–0.9 m^3	Wastewater	0.2–0.9 m^3
Electricity	0.4–1.5 kW.h	COD	7–15 kg
Cans	NA	Heads and entrails	150 kg
		Bones and meat	100–150 kg

Table 3–20 Input and output data for skinning of nobbed fish

Inputs		Outputs	
Nobbed fish	1000 kg	Skin-less nobbed fish	940 kg
Water	17 m^3	Wastewater	17 m^3
Chemicals	NaOH (8%)	COD	3–5 kg
Electricity	NA	Waste (skin)	~ 55 kg

Environmental issues

The main environmental issues associated with this aspect of the process are the use of water and the potential for high organic load in the wastewater stream.

Water is used continuously for the cleaning of knives and equipment and, in some instances, to align the fish.

The offal contains oil and easily dissolved organic material that can contribute a significant organic load to the wastewater. If the offal is transported away using water flumes, the potential organic load is even more significant.

Cleaner Production opportunities

Instead of nobbing the fish, the guts can be removed using vacuum suction. The entrails and offal can be transported to collection facilities or to the fish meal plant in an enclosed system instead of using water flumes. This can reduce both water consumption and the COD load of the resulting wastewater by about 67%. However, the capital investment required for this system is high.

Alternatively, installing water-efficient spray nozzles and solenoid-controlled shut-off valves can reduce water consumption by up to 50%. The capital investment required for this option is quite low.

When filling the cans with fish, caution should be taken not to contaminate the outer surface of the cans unnecessarily, because this will necessitate more washing of the cans before retorting. This good housekeeping option costs nothing, and reduces the consumption of water and chemicals for washing the cans.

Case Study 3–6: Sorting of raw material

In the production of canned smoked sprats a grader was introduced to sort the raw material according to size.

This resulted in:

- fewer fish losses during smoking;
- higher yield when de-heading;
- better quality due to more uniform smoking.

Case Study 3–7: Water savings in a cannery

A cannery with a processing capacity of 35–40 tonnes of fish per hour initially used 210 m^3 water per hour. An assessment revealed that one of the main areas of water use was overflow at the fish pits, because the supply line did not close properly. A 'gooseneck' was fitted to the outlet to stop the excess water flow. In addition, better nozzles were installed at the cutting and filling machines. As a result of these changes, water consumption was reduced to 70 m^3/h.

3.2.3 Precooking and can draining

Process description

Smaller fish species are precooked in the can. However, medium- and large-sized fish species are precooked before being canned to avoid the production of a cloudy sauce or brine. This section discusses the pre-cooking process.

Cooking most often takes place in water-filled cookers. After cooking, the inedible parts of the fish are removed by peeling or by cutting. The edible parts are then packed into the can. The cans are then drained to remove any expelled liquid.

Inputs and outputs

Figures 3–12 and 3–13 are flow diagrams showing the inputs and outputs from these processes. Tables 3–21 and 3–22 provide data for the key inputs and outputs.

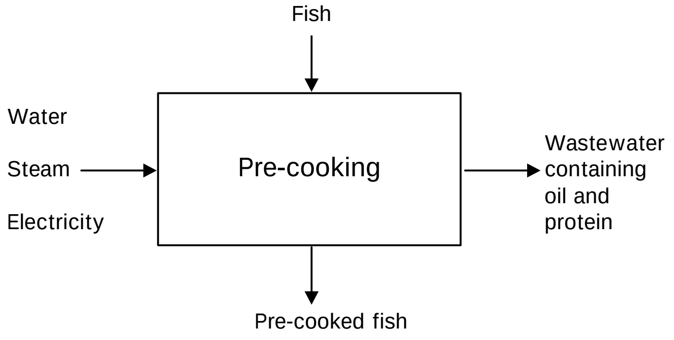

Figure 3–12 Inputs and outputs for precooking

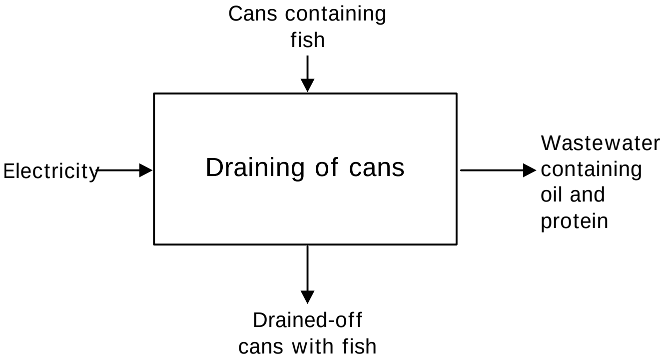

Figure 3–13 Inputs and outputs for draining of cans after pre-cooking

Table 3–21 Input and output data for precooking of fish to be canned

Inputs		Outputs	
Raw fish	1000 kg	Precooked fish (without cans)	850 kg
Steam for heating	35–560 kg	Wastewater	0.07–0.27 m^3
Electricity	0.3–1.1 kW.h	Solid waste (inedible parts)	150 kg

Note that the minimum figure for steam consumption of 35 kg (corresponding to ~28 kW.h) is for precooking of small cans containing no water, in a closed precooker. The high figure of 560 kg (corresponding to ~440 kW.h) is for fish precooked in tall cans containing water.

Table 3–22 Input and output data for draining of cans containing pre-cooked fish

Inputs		Outputs	
Cans with fish	1000 kg	Drained cans with fish	800–900 kg
Electricity	0.3 kW.h	Wastewater	0.1–0.2 m^3
		COD	3–10 kg

Environmental issues

Water is used for filling cookers and for steam production, and is sometimes added to larger cans to assist in the draining of the expelled liquid.

When the larger fish species are precooked in vats of water, oil, protein and pieces of fish are released into the water, with the oil forming a layer on the surface. When the small species of fish are cooked in cans, 10–20% of the fish weight is released as cooking water and is subsequently drained out of the can.

The liquid generated from the cooking process contains dissolved proteins and oil, with the oil content depending on the type of fish. Approximately 3–4 g oil per kilogram of fish can typically be released from oily fish, but it can also be as much as 10 g. Cooking liquids are normally discharged to the drain.

Another environmental issue associated with the cooking process is the large amount of energy used.

Cleaner Production opportunities

The cooking water can be reused repeatedly if the oil is skimmed off and the oil can be sold for fish oil production. The capital investment required for this option is low.

Cookers should always be covered and insulated to reduce heat loss. Proper insulation can be costly, but will normally pay back its costs within a few years.

Cookers should be insulated, and designed so that steam loss is minimised. Installation of a damper in the exhaust of the cooker, combined with automatic or manual control, can also be effective in reducing steam losses.

As an alternative, microwave cooking has been introduced in some plants for pre-cooking processes. The investments required are high, but water consumption is almost eliminated and energy consumption is reduced considerably, especially for fish in tall cans. Microwave cooking may increase product yield, but the process needs careful examination before changes are implemented because it may change the quality of the product.

Skimming of the oil from the cooking liquors will increase the income from selling the oil. This requires no investment, only a change in working procedures. The aqueous phase left after oil skimming can be used for production of fish soup.

As liquid is drained off it should be collected in a storage vessel. The liquid is warm, so the oil separates easily and can be removed from the surface by scraping or suction. This can significantly reduce the pollution load of wastewaters generated from the processing of oily species, and the oil can be sold as fish oil. It is much more efficient to recover the oil from the liquid immediately after draining, rather than at a later stage, as some of it will be emulsified in the water.

For large-scale production it is possible to use a centrifuge to separate the oil, but the investment required is high and requires large volumes to be cost effective.

3.2.4 Sauce filling, sealing and washing of cans

Process description

After being drained, the cans continue to the filling station where they are filled with sauce or brine, and then to the can sealer. The cans are washed to remove fish remains and sauces from the surface, which otherwise could stick when heated in the retort. The amount of water needed for washing depends on how the fish and cans were handled when the fish were packed into the cans. The need for washing increases if the operators touch the outsides of the cans unnecessarily, and when the flesh is soft and breaks easily.

Inputs and outputs

Figure 3–14 is a flow diagram showing the inputs and outputs from this process. Tables 3–23, 3–24 and 3–25 provide data for the key inputs and outputs.

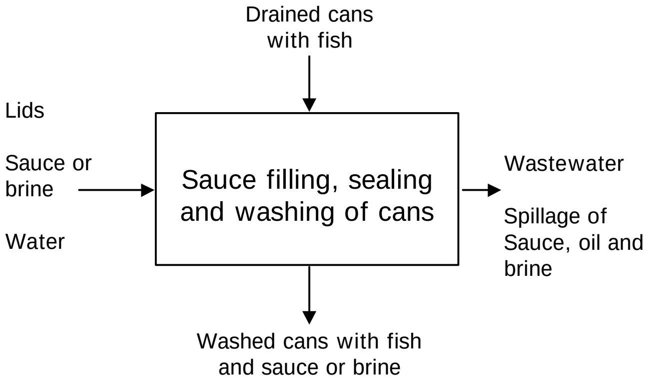

Figure 3–14 Inputs and outputs for sauce filling, sealing and can washing

Table 3–23 Input and output data for sauce filling

Inputs		Outputs	
Drained cans containing fish	1000 kg	Cans containing fish and sauce	1100 kg
Sauce and additives	NA	Waste (spillage of sauce and oil)	varies

Table 3–24 Input and output data for can sealing

Inputs		Outputs	
Cans with fish and sauce	1000 kg	Sealed cans	1000 kg
Electricity	5–6 kW.h		

Table 3–25 Input and output data for washing of cans

Inputs		Outputs	
Sealed cans	1000 kg	Washed cans	1000 kg
Water	0.04 m^3	Wastewater	0.04 m^3
Electricity	7 kW.h		

Environmental issues

The main issues are spillage of sauce, brine or oil added to the cans, and the consumption of water for washing of cans. All losses end up in the wastewater.

Cleaner Production opportunities

A sufficiently large tray to catch spillage from the filling machine should be installed. The filling machine should be well adjusted to minimise the spillage.

Cooling water from the retort or from the flotation plant can be used for washing the closed cans. This necessitates only some piping, so the required capital investment is low. The expected water savings are 0.4 m^3/t RM.

3.2.5 Can sterilisation

Process description

The purpose of sterilisation is to preserve the product. Cans are placed in baskets in a retort and heated to a set temperature for the required time to ensures proper sterilisation. A retort is a vessel that can be sealed and pressurised, containing water which is heated with steam. After sterilisation, cans are cooled to 25°–35°C with chlorinated water.

Inputs and outputs

Figure 3–15 is a flow diagram showing the inputs and outputs from this process. Table 3–26 provides data for the key inputs and outputs.

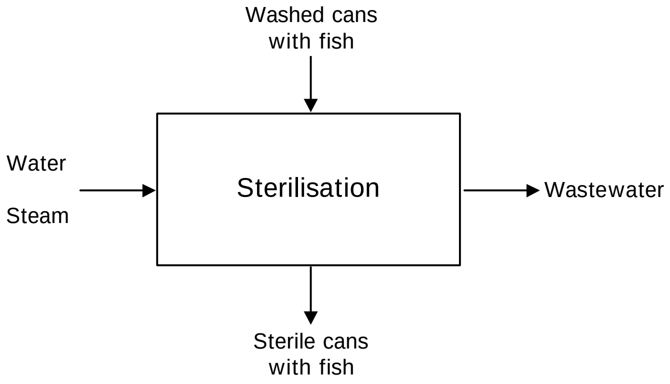

Figure 3–15 Inputs and outputs for can sterilisation

Table 3–26 Input and output data for sterilisation of cans

Inputs		Outputs	
Washed cans with fish	1000 kg	Sterile cans with fish	920–990 kg
Water	3–7 m^3	Wastewater	3–7 m^3
Steam	290 kg (~230 kW.h)	Damaged cans	10–80 kg

Environmental issues

Typically the energy consumption is 200–240 kW.h per tonne of canned product. The energy consumption is a major environmental issue, as it causes resource depletion and air pollution.

Water is used for production of steam and cooling of cans.

Cleaner Production opportunities

Water-filled retorts without a water storage facilities use approximately 75% more energy than retorts with water storage facilities. Therefore the installation of a storage tank should be considered if not already in place. The required capital investment is low, and savings are very substantial: approximately 173 kW.h and 5–6 m^3 of water per tonne RM.

Another energy-saving measure is insulation of the retort, which can save 1.4 kg fuel per tonne of canned product. This measure is costly, at around US$16,000.

Instead of discharging the water to the drain, the water can be directed to a cooling tower and reused for cooling. The number of times water can be reused depends on how clean it is maintained. The water can become contaminated with broken cans and dirt from the surface of the cans. Damaged cans should be removed before placed into the retort to avoid contamination of the water.

When the water can no longer be recirculated, it could be used to clean the sealed cans and for other cleaning activities. The investment required for installation of the necessary pipes and pumps is fairly low, and about 85% of the water can be reused.

3.3 Fish meal and fish oil production

Fish meal production consists of a dry and a wet process. Fish meal is produced in the dry process, and fish oil from the wet process.

3.3.1 Handling and unloading of fish

Process description

Fish for fish meal and fish oil production are caught in large shoals and stored in bulk on the vessel until they can be transported to the plant.

Fish are commonly unloaded from the fishing vessel to the processing plant using a 'wet' unloading method. The fish are pumped out of the vessel's hold and conveyed to the plant in gravity flumes, which float the fish in water. The water, referred to a bloodwater, is drained off, and the fish are weighed and then released into the storage pits inside the plant. Some plants treat the bloodwater through a screen or flotation tank before being discharged to the ocean.

Inputs and outputs

Figure 3–16 is a flow diagram showing the inputs and outputs from this process. Tables 3–27 and 3–28 provide data for the key inputs and outputs for the handling and storage, and unloading of fish respectively.

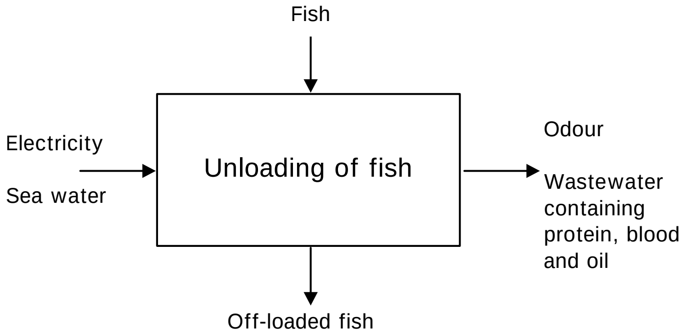

Figure 3–16 Inputs and outputs for unloading of fish

Table 3–27 Input and output data for handling and storage of fish

Inputs		Outputs	
Fish catch	1000 kg	Quantity of fish unloaded	850–870 kg
Electricity	10–12 kW.h	COD	130–140 kg
Ice	200 kg		

Table 3–28 Input and output data for unloading of fish

Inputs		Outputs	
Fish	1000 kg	Off-loaded fish	750–1000 kg
Water	2–5 m^3	Wastewater	2–5 m^3
Electricity	3 kW.h	COD	27–34 kg

Environmental issues

Fish rapidly deteriorate leading to softening of the meat and formation of considerable amounts of bloodwater containing protein and oil. Bloodwater can be heavily contaminated by organic matter, depending on the quality and type of fish. The COD of the bloodwater is normally 15,000–70,000 mg/L but can attain several hundreds of thousands of mg per litre.

Cleaner Production opportunities

Handling of the catch on board the vessel is not under the direct control of the fish meal plants, but has a significant impact on the pollution arising from production.

In some industries, the quality of the raw fish is used to set the price paid and this encourages the fishing companies to take better care of the catch. A higher yield can be expected in processing due to higher quality inputs.

The best way of preserving the catch is by chilling. This can be done using cooling systems that use mechanically refrigerated sea water, or by mixing the fish with ice. Mixing with ice can be done manually, but is better done automatically. The chilling will give a better fish meal quality and the oil yield can be increased up to 50%.

Case Study 3–8: Reduction of pollution from Danish fish meal plants

Fish meal plants in Denmark have over a number of years been forced to reduce their overall pollution by 80% or 6200 tonnes COD/year. Improving the quality of the raw material has been one of the most important ways of achieving this reduction. Other ways of minimising pollution have been to improve the efficiency of the pressing, decanting and centrifuging processes. It has also been necessary to improve filtering and wastewater treatment.

Dry unloading, using pneumatic off-loaders or elevators, can be used instead of wet unloading. The investment required for dry unloading is high, but energy consumption may be reduced by 25–50%.

Bloodwater should, if possible, be evaporated with the stickwater in the evaporation plant (see Section 3.4.9). Alternatively, the bloodwater can be collected and sent to the fish meal and fish oil plant, where the solid material is recovered in the decanter for subsequent recovery as fish meal (see Section 3.4.6).

3.3.2 Cooking

Process description

Fish are conveyed through a continuous cooker by means of a rotary screw conveyor and cooked at a temperature of 95°–100°C as it travels through the cooker. Heat is applied to the cooker indirectly through a steam-heated jacket that surrounding the screw conveyor.

Inputs and outputs

Figure 3–17 is a flow diagram showing the inputs and outputs from this process. Table 3–29 provides data for the key inputs and outputs.

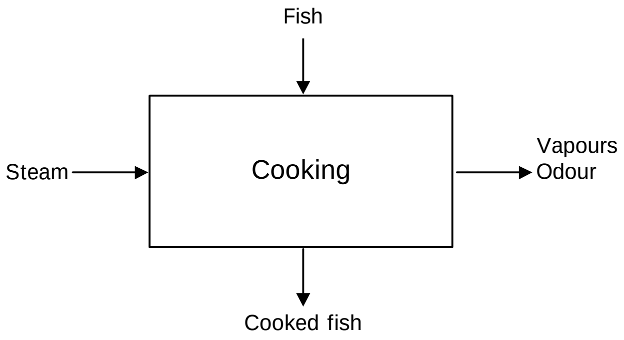

Figure 3–17 Inputs and outputs for cooking fish

Table 3–29 Input and output data for cooking of fish

Inputs		**Outputs**	
Fish	1000 kg	Cooked fish	1000 kg
Steam	115 kg (~90 kW.h)		

Environmental issues

The process consumes considerable amount of energy and can generate odours.

Cleaner Production opportunities

Energy consumption can be reduced by cleaning the internal surfaces of the cooker at regular intervals to avoid the accumulation of deposits on the heated surfaces, which would otherwise inhibit heat transfer. Energy consumption can be further reduced through careful control of the cooker temperatures.

Waste heat from the evaporators and dryers (used in subsequent processes) can be used to pre-heat the material up to approximately 50°C. The required capital investment is low compared with the savings in energy consumption.

Odorous fumes can be ducted to the boiler and incinerated, which substantially reduces odour problems. The required capital investment is relatively low.

3.3.3 Straining and pressing

Process description

The cooking process releases oil and water from the solid mass. The released liquids are drained from the mass in a strainer. Most of the oil and water can be separated from the solid phase by this straining process, however more can be removed by treating the solid phase in a press or centrifuge. Reducing the moisture content of the solid fish cake helps to reduce fuel consumption during subsequent drying steps.

The products from this process are press cake (the solid material) and the oily water. The subsequent drying and milling of the press cake to produce fish meal are discussed in Sections 3.4.4–3.4.5, and the further processing of the oily water to produce fish oil are discussed in Sections 3.4.6–3.4.8.

Inputs and outputs

Figure 3–18 is a flow diagram showing the inputs and outputs from this process. Table 3–30 provides data for the key inputs and outputs.

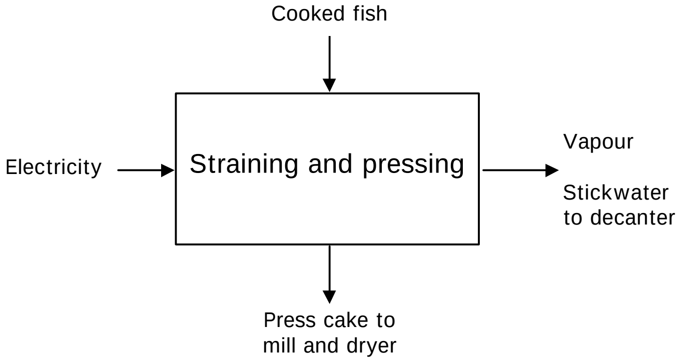

Figure 3–18 Inputs and outputs for pre-straining and pressing

Table 3–30 Input and output data for pressing the cooked fish

Inputs		**Outputs**	
Cooked fish	1000 kg	Stickwater	750 kg water
Electricity	NA		150 kg oil
		Press cake	100 kg dry matter

Cleaner Production opportunities

For most raw materials, apertures of 4–6 mm diameter in the strainer are suitable. Substantially larger diameters will cause problems, as the large particles allowed to pass through the strainer will tend to block the pump conveying the liquid. The presence of solid material in the screened liquid will also reduce the efficiency of subsequent steps. By ensuring the optimum diameter for the screen apertures, better performance and higher yield will be obtained.

Problems may occur when soft, partly deteriorated fish are processed. Poor quality materials contain large amounts of fine particulate matter (sludge), which tend to clog up the outlets of the press. If better raw material cannot be obtained, the size of the holes in the pre-strainer should be increased.

Increasing the pressure of the press will improve the recovery of liquid.

3.3.4 Drying of press cake

Process description

The purpose of drying is to convert the wet press cake into a stable, preserved meal. The sludge from the decanter (see Section 3.4.6) is also added to the press cake before drying.

Drying may take place using either direct-fired drying or indirect steam drying. For direct-fired drying, hot air is passed through the dryer and comes in direct contact with the press cake. This is the most efficient mode of heat transfer, but it is more difficult to control than other methods. For the indirect steam drying, the press cake is fed continuously into a rotary apparatus containing steam-heated elements (tubes, discs, coils etc.). A counter-current stream of air is blown through the dryer to remove water vapour. Indirect steam drying is less energy efficient than direct-fired drying.

Odourous gases released from the drying process, along with those from other parts of the process (cookers, strainers, presses etc.), are often treated before being released.

Inputs and outputs

Figure 3–19 is a flow diagram showing the inputs and outputs from this process. Table 3–31 provides data for the key inputs and outputs.

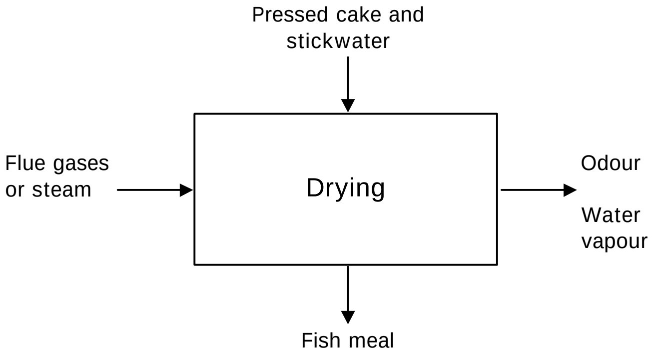

Figure 3–19 Inputs and outputs for drying

Table 3–31 Input and output data for drying

Inputs		Outputs	
Press cake and stickwater	1000 kg	Fish meal	480 kg (12% moisture)
Steam	430 kg (~340 kW.h)	Vapour	~520 kg

Environmental issues

The process uses large amounts of energy for heating, and can cause highly objectionable odours.

Cleaner Production opportunities

In modern indirect steam dryers, heat can be recovered and used in the evaporation plant (see Section 3.4.9). This saves considerable amounts of energy, but requires installation of piping and heat exchangers.

The temperature in indirect steam dryers should be carefully controlled to avoid scorching of the fish meal, which greatly exacerbates odour problems.

High-temperature combustion of the odourous gases from the dryers is a very efficient and relatively cheap method for dealing with odourous emissions. The gaseous emissions can be collected and burnt in the boiler. This method is most easily used at plants which use dry indirect steam dryers, since there is usually a boiler on site.

Saltwater scrubbers can also be used to reduce odour. Cool waters recirculated in the scrubber acts to condense the vapours and reduces the gas volume by some 40%. The gases exiting the scrubber may also be chemically denatured using hypochlorite as the oxidising agent.

3.3.5 Milling and packaging of fish meal

Process description

Dried fish meal first passes through a sieve to remove extraneous matter and is then milled before being automatically weighed into bags for distribution and sale.

Inputs and outputs

Figure 3–20 is a flow diagram showing the inputs and outputs from this process. Table 3–32 provides data for the key inputs and outputs.

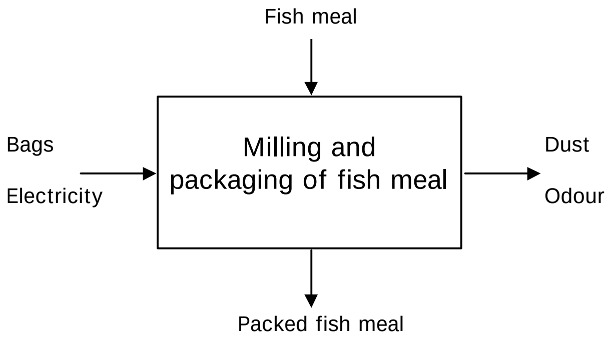

Figure 3–20 Inputs and outputs for milling and packing of fish meal

Table 3–32 Input and output data for milling and packing of fish meal

Inputs		Outputs	
Fish meal	1000 kg	Packed fish meal	1000 kg
Electricity	NA	Dust	NA
Bags	NA	Odour	NA

Environmental issues

Dust and odour emitted from the milling processes may cause some localised annoyance as well as an unhealthy work environment for operators.

Cleaner Production opportunities

The mill should be regularly cleaned to avoid clogging and regularly maintained to help avoid spillages.

Odour gases from the milling process should be extracted for treatment along with the other odourous steams before being released.

3.3.6 Decanting of press liquid

Process description

Press liquid from the straining and pressing process (see Section 3.4.3) is transferred to a decanter, along with bloodwater from the unloading of fish (see Section 3.4.1). The decanter is a horizontal centrifuge with two- or three-phase separation.

The first phase removes about half of the dry matter from the press water (which contains approximately 10% dry matter before decanting) which is sent to the dryer (see Section 3.4.4). In the second phase, water containing sludge is removed. In the third phase, decanter liquid (impure oil) is separated. The liquids flow through a closed system and no pollution should occur from this step.

Figure 3–21 is a flow diagram showing the inputs and outputs from this process. Table 3–33 provides data for the key inputs and outputs.

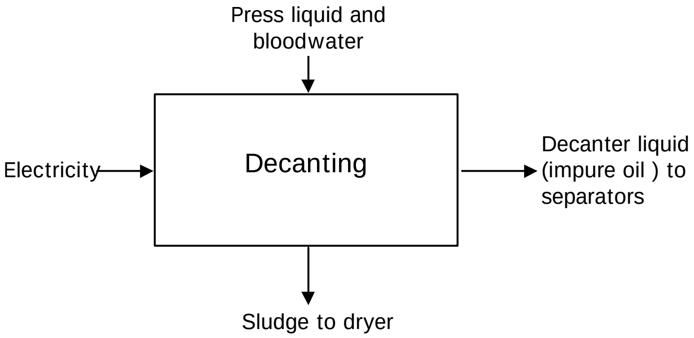

Figure 3–21 Inputs and outputs for decanting of press liquid

Table 3–33 Input and output data for decanting of press liquid

Inputs		Outputs	
Press liquid and bloodwater	1000 kg	Impure oil (decanter liquid)	900 kg
Electricity	NA	Sludge to dryer	100 kg

Cleaner Production opportunities

If the decanter and pumps are old, changing to newer, more energy-efficient equipment should be considered. Equipment specifications can be obtained from various suppliers in order to compare the stated energy consumption rates.

3.3.7 Centrifugation of decanter liquid

Process description

In this step, decanter liquid (impure oil) is centrifuged further to separate the fish oil from the aqueous phase. The resulting wastewater from the process is referred to as stickwater.

After centrifugation, the stickwater contains 5–10% dry matter and 1% oil. The stickwater is then pumped to the evaporators and the oil is sent for further processing.

Inputs and outputs

Figure 3–22 is a flow diagram showing the inputs and outputs from this process. Table 3–34 provides data for the key inputs and outputs.

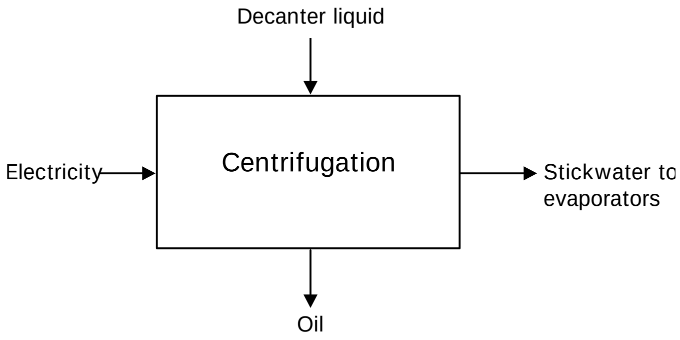

Figure 3–22 Inputs and outputs for heating and centrifugation

Table 3–34 Input and output data for centrifuging of the decanter liquid

Inputs		Outputs	
Decanter liquid	1000 kg	Oil	10 kg
Electricity	NA	Stickwater	900–950 kg water
			50–100 kg dry matter

Environmental issues

The average COD of stickwater is more than 100,000 mg/L and causes significant pollution if discharged. In some places or under some conditions, stickwater is discharged to sewer.

Cleaner Production opportunities

Since stickwater represents a substantial pollution load and a loss of product, it is important to ensure that all stickwater is transferred to the evaporators and used in production. This does not require any capital investment—just a good knowledge of the equipment and processes.

3.3.8 Fish oil polishing

Process description

The purpose of this process is to refine or ‘polish’ the oil extracted from the decanting process. Polishing is carried out by extracting impurities from the oil using hot water at about 95°C.

Figure 3–23 is a flow diagram showing the inputs and outputs from this process. Table 3–35 provides data for the key inputs and outputs.

Environmental issues

Hot water is used for polishing, thus this process is energy consuming. The energy consumption depends on the amount of water used and whether the hot water is generated from waste heat (e.g. from drying) or from steam.

The polishing process generates a low-volume, high-strength effluent. The volume of this effluent is about 0.07 m^3 per tonne processed and the effluent quality, measured as COD, varies between 20,000 and 200,000 mg/L.

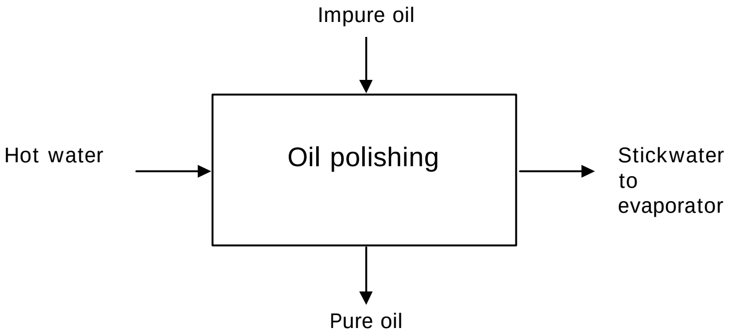

Figure 3–23 Inputs and outputs for oil polishing

Table 3–35 Inputs and outputs for oil polishing

Inputs		**Outputs**	
Impure oil	1000 kg	Pure oil	~1000 kg
Water	0.05–0.1 m^3	Wastewater	0.05–0.1 m^3
Energy	hot water	COD	~5 kg

Cleaner Production opportunities

The use of waste heat for this and other processes will reduce energy consumption, and will also help to reduce the temperature of the wastewater. Waste heat recovery requires a heat exchanger, an insulated hot water tank and the necessary piping.

The effluent should be collected and sent to the evaporators, to prevent the discharge of highly polluted liquid.

3.3.9 Stickwater evaporation

Process description

The stickwater from the centrifuges and oil polishing process is concentrated in an evaporation unit. Normally, a multi-stage evaporator is used, where the pressure is successively lowered and waste heat from the previous phases is reused. From each phase, stickwater concentrate or condensed fish solubles are drawn off. The remaining solution (50–60% water) is added to the press cake in the dryer from where the end product, fish meal, is produced.

Two types of evaporators are used:

- Falling film evaporators, with no recirculation and short retention times, are effective at handling heat-sensitive products.
- Circulating evaporators can operate over a wide range of concentrations in a single unit. Self-circulating evaporators are normally less energy efficient than forced-circulation and falling film evaporators.

The stickwater plant needs to be cleaned at regular intervals, either mechanically or by using caustic soda.

Inputs and outputs

Figure 3–24 is a flow diagram showing the inputs and outputs from this process. Table 3–36 provides data for the key inputs and outputs.

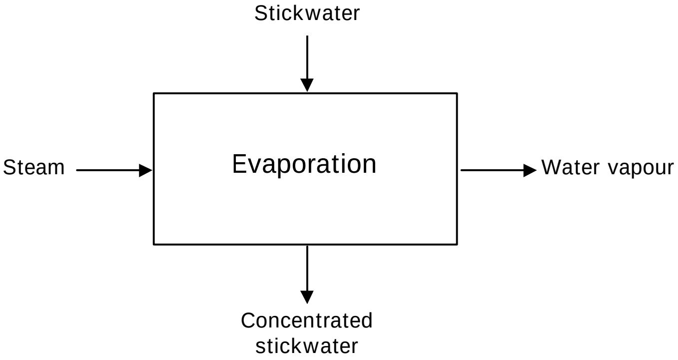

Figure 3–24 Inputs and outputs for evaporation

Table 3–36 Material balance for evaporation of stickwater

Inputs		**Outputs**	
Stickwater	1000 kg	Concentrated stickwater	250 kg
Steam	600 kg (~475 kW.h)	Dry matter Water vapour	up to 50 kg ~700 kg

Environmental issues

As the water evaporates, the viscosity of the stickwater increases and this in the end determines how high a concentration can be obtained. If bumping occurs during heating, there is a risk that material will be carried away with the steam, thus resulting in increased air emissions. Approximately 25% of the dry matter from the fish will pass through the evaporators. The pollution is thus increased greatly when the stickwater plant is not running. Processing 1000 kg of fish with a dry matter content of 20% will yield 200 kg of dry matter. If the stickwater is not used, 50 kg of dry matter will be discharged.

Significant quantities of energy are used to evaporate the water. Typically, figures for steam consumption are 0.40–0.45 kg steam per kilogram of water evaporated in a triple effect evaporator.

Cleaner Production opportunities

The nature of the stickwater is such that the evaporator tubes are easily fouled, with consequent reduction in thermal efficiency and capacity. The evaporators should therefore be cleaned frequently to restore efficiency. When a processing plant is operated at full capacity for many hours, declining performance and cleaning of the evaporators result in an accumulation of stickwater and bloodwater, which ultimately must be discharged if the plant is not shut down during the cleaning process. Stickwater condensate can be used for flushing and cleaning before and after caustic soda treatment. The liquid can be collected and evaporated in the evaporation plant. Thus, discharge of highly polluting stickwater is avoided without capital investment.

Modern falling film evaporators have a shorter retention time and low hold-up volumes. This makes them more efficient to start up for small-scale production. The investments necessary for reusing the surplus heat are low (the requirements are a heat exchanger, a hot water storage tank and piping). It is more costly to install new evaporators; however, both options will reduce energy consumption.

3.3.10 Acid hydrolysis to produce silage

Instead of using fish waste to produce fish meal and oil, it can be converted into silage, which can be used as a nutritious animal feed. Fish silage is a liquefied fish product produced by grinding and acid hydrolysis of fish or fish scrap. The acid hydrolysis process breaks the fish proteins down to single amino acids and small peptide fragments.

Production of silage is a good option when there is animal farming nearby. The feed can be used for pigs, poultry and ruminants. The silage is added to the feed mixture in different amounts (5–20% by weight) depending on species and age of the animal.

Besides its high nutritional value, an advantage of silage is that the processing is simple, with no requirement for specialised equipment, and required capital investment is low. It can be carried out at small and large installations.

3.3.11 Protein hydrolysates

An alternative to producing silage by acid hydrolysis is to use enzymatic hydrolysis to produce protein hydrolysates. This process allows the hydrolysis to be controlled so that not all the proteins are hydrolysed down to single amino acids, producing a better and more palatable feed ingredient.

Enzymatic hydrolysis also operates under acid conditions. However proteolytic enzymes are added to the minced fish along with minerals or organic acids. The mixture is heated to 65^{o}C to solubilise the protein.

Compared with acid hydrolysis, this process involves considerable capital and technical investment, which might not be attractive for small or seasonal operations.

3.4 Cleaning

Process description

In a fish processing plant work areas and equipment that are in contact with fish must be cleaned and sanitised regularly to maintain hygienic conditions. Cleaning requirements are normally stipulated by regulation. All production areas and equipment are cleaned daily, and the floors and machinery are also rinsed during production.

A common cleaning routine at fish processing plants is to first hose down equipment and floors roughly, to enhance the effect of detergents. Detergents and sanitising agents are then applied, followed by washing and scrubbing. The detergents used are normally alkaline, in order to remove oil and protein. There is a final rinse with clean water to remove all detergent and sanitising agents.

Inputs and outputs

Figure 3–25 is a flow diagram showing the inputs and outputs from this process.

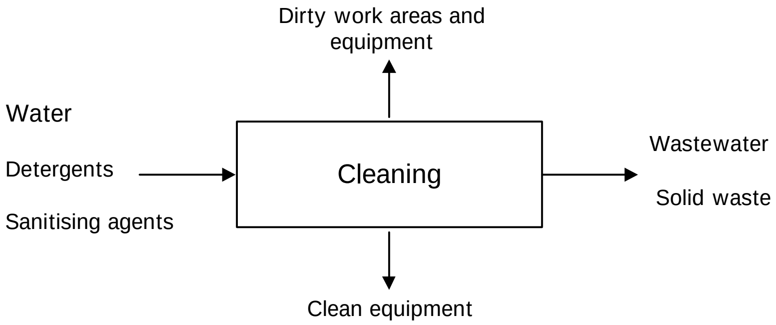

Figure 3–25 Inputs and outputs for cleaning

Environmental issues

The water consumption for cleaning can be very high accounting for 25–40% of the total water used at a fish processing plant.

The organic load contained in cleaning wastewater is high, containing fish wastes which have been washed to the drain. Cleaning wastewaters also contain detergents and disinfectants. In addition, hazardous substances such as sodium hydroxide and sodium hypochlorite are sometimes used in conjunction with cleaning.

Cleaner Production opportunities

A large part of the water for cleaning—about 70%—is consumed during the initial rinse step. Therefore this is an areas where significant water savings can be made The best way of reducing water consumption for cleaning is to undertake dry cleaning before washing with water.

Solid materials should first be scraped and swept from all surfaces and floors. Following thorough dry cleaning, work surfaces, walls and floors can be washed down in preparation for cleaning and sanitising. The following measures will help reduce water consumption for this step:

- hoses should be fitted with spray nozzles, since a pressurised spray is far more effective for cleaning surfaces and therefore uses less water. A pressure of 25–30 bar is advisable.
- flat-jet nozzles provide maximum impact and velocity for any given pressure. Spray angles of up to 60° provide wide coverage and a sweeping effect to propel remaining solids towards floor drains.
- the first rinse should be with cold water, because warm water will make protein materials stick to the surfaces. The temperature of the water for the subsequent cleaning depends on the kind of contamination; however cold water is often sufficient.
- the wastewater from the final rinse can be collected and used for the initial rinse on the following day.

Detergents and disinfectants can be a significant source of pollution if the amounts used are too great. It is very important, therefore, to monitor their consumption.

The following measures will help reduce detergent consumption:

- determining the required amount or concentration for effective cleaning;
- scraping followed by an initial rinse. This will reduce the consumption of detergents for dissolving organic matter and oil;
- applying detergents in a certain ratio with water, so a reduction in water consumption will reduce the consumption of detergents;
- using newer detergents, some of which are more effective and more environmentally friendly than older ones. alternative detergents should be evaluated on the basis of their cleaning performance as well as their cost and environmental attributes.

Sanitisers should be applied as a fine spray to cleaned surfaces, instead of a final rinse with hot water (about 82°C). Chemical sanitisers can be more effective in bacteriological control, less damaging to the building and safer for personnel than large quantities of hot water (McNeil and Husband, 1995).

Spray nozzles, commonly used for cleaning operations, are subject to wear that causes deterioration of the orifice and distortion to the spray pattern. This results in an increased flowrate of water and reduced effectiveness. In general, 10% nozzle wear will result in a 20% increase in water consumption (McNeil and Husband, 1995).). Nozzles made from different materials have varying abrasion resistance, as shown in Table 3–37.

Table 3-37 Abrasion wear index for nozzle materials [1]

Material	Abrasion wear index
Brass	1 (poor)
Stainless steel	4–6 (good)
Hard plastics	4–6 (good)
Ceramic	90–200 (excellent)

[1] McNeil and Husband, 1995

Regular monitoring of spray nozzle wear should be incorporated into maintenance programs. Nozzles in service can be compared with new nozzles to determine the extent of wear, and the flowrate of a nozzle can be determined by measuring the time taken to fill a container of known volume.

Case Study 3–9: Cleaning in a herring processing factory

At a Danish herring processing plant, cleaning equipment consists of two 500 L water storage containers, two pumps, a flow meter, a timer and various valves. One of the two containers is first filled with clean water and used to commence cleaning of plant equipment. The cleaning wastewaters drain through the filter conveyor and are pumped back into the water storage container. When the flow meter has measured consumption of four times the container volume (about 2 m^3), the second water storage container, which has been filled with clean water in the meantime, is used as the water supply. The first container is then refilled with clean water, and so on, so that the cleaning process proceeds uninterruptedly.

The use of this system has reduced fresh water consumption for cleaning in the herring processing plant by 75%. This type of cleaning system could be used for plants processing white fish as well.

3.5 Ancillary operations

3.5.1 Compressed air supply

Air is compressed in an air compressor and distributed throughout the plant in pressurised pipes. Normally, the compressor is driven by electricity and cooled with water or air.

Inputs and outputs

Figure 3–26 is a flow diagram showing the inputs and outputs for this process.

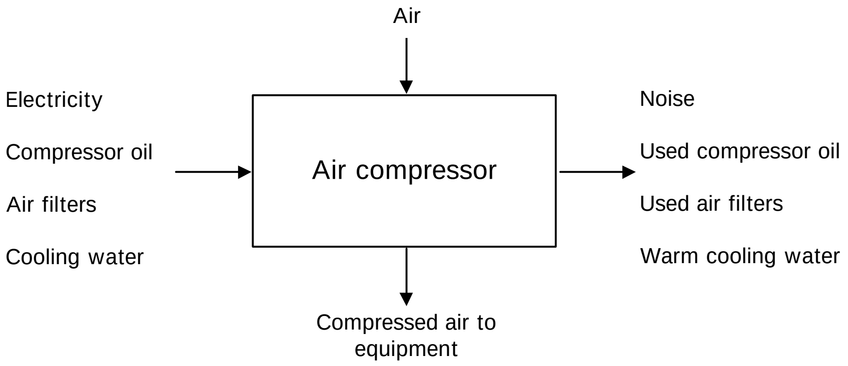

Figure 3–26 Inputs and outputs for production of compressed air

Environmental issues

With just a few small holes in the compressed air system (pipes, valves etc.), a large amount of compressed air is continuously lost. This results in a waste of electricity because the compressor has to run more than is necessary. Table 3–38 lists unnecessary electricity consumption that can be caused by leaks in the compressed air system.

Table 3–38 Electricity losses from leaks in 6 bar compressed air system [1]

Hole size (mm)	Air losses (L/s)	kW.h/day	MW.h/year
1	1	6	3
3	19	74	27
5	27	199	73

[1] UNEP, 1996

Air compressors are usually very noisy, causing serious risk of hearing damage to the workers in the area.

If the air compressor is water cooled, water consumption can be quite high.

Cleaner Production opportunities

It is very important to check the compressed air system frequently. The best method is to listen for leaks during periods when there is no production.

Maintenance (e.g. change of compressor oil) and the keeping of accurate log-books will often help identify the onset of system leaks.

A great deal of energy can be saved through these simple measures. It pays to implement procedures that ensure the compressed air system is leak free and well maintained.

The consumption of cooling water should be regulated by a temperature-sensitive valve, ensuring the optimum cooling temperature and minimum use of water. Furthermore, the cooling water can be recirculated via a cooling tower. Alternatively, the cooling water can be reused for other purposes such as cleaning, where the hygiene requirements are low.

Case Study 3–10: Reuse of cooling water

An air-cooled system for an air compressor was replaced with a water-cooled one. The water absorbs the heat from the compressor and is then reused in the boilers. Energy is saved in the boilers because the water preheated.

The installation of the water cooling system cost US$18,000 and had a payback period of less than two years.

3.5.2 Steam supply

Process description

Steam is produced in a boiler and distributed throughout the plant by insulated pipes. Condensate is returned to a condensate tank, from where it is recirculated as boiler feed water, unless it is used for heating in the production process.

Inputs and outputs

Figure 3–27 is a flow diagram showing the inputs and outputs for this process.

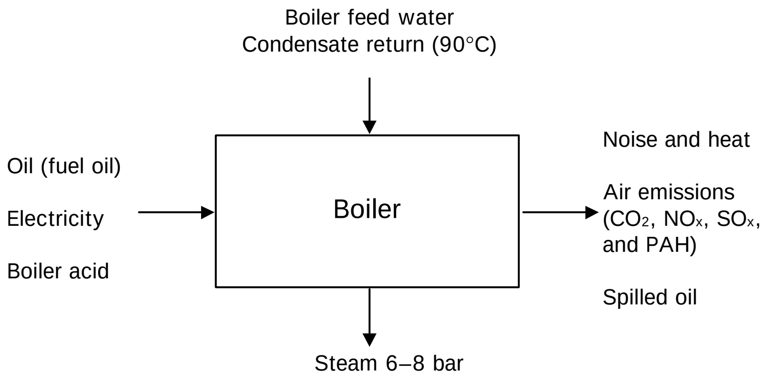

Figure 3–27 Inputs and outputs for supply of steam

The amount and pressure of the steam produced depend on the size of the boiler and how the fuel is injected into the combustion chamber. Other parameters include pressure level, fuel type, and maintenance and operation of the boiler.

Environmental issues

Inefficiencies in boiler operation of boilers and steam leaks leads to the waste of valuable fuel resources as well as additional operating costs.

Combustion of fuel oil results in emissions of carbon dioxide (CO_2), sulphur dioxide (SO_2), nitrogen oxides (NO_x) and polycyclic aromatic hydrocarbons (PAHs). Some fuel oils contain 3–5% sulphur and result in sulphur dioxide emissions of 50–85 kg per 1000 litres of fuel oil.

Sulphur dioxide converts to sulfuric acid in the atmosphere, resulting in the formation of acid rain. Nitrogen oxides contribute to smog and can cause lung irritation.

If the combustion is not adjusted properly, and if the air:oil ratio is too low, there are high emissions of soot from the burners. Soot regularly contains PAHs that are carcinogenic. Table 3–39 shows the emissions produced from the combustion of various fuels to produce steam.

Table 3–39 Emissions from the combustion of fuel oil

Input		**Outputs**	
Fuel oil (1% sulphur)	1 kg	Energy content	11.5 kW.h
		Carbon dioxide (CO_2)	3.5 kg
		Nitrogen oxides (NO_x)	0.01 kg
		Sulphur dioxide (SO_2)	0.02 kg

1 kg of oil = 1.16 litre of oil (0.86 kg/L)

1 kW.h = 3.6 MJ

Oil is often spilt in storage and at the boiler. If the spilt oil is not collected and reused or sold, it can cause serious pollution of soil and water.

Cleaner Production opportunities

Instead of using fuel oil with a high sulphur content, it is advantageous to change to a fuel oil with a low sulphur content (less than 1%). This increases the efficiency of the boiler and reduces sulphur dioxide emissions. There are no investment costs involved, but the running costs will be higher because fuel oil with a lower sulphur content is more expensive.

It is essential to avoid oil spills and, if they occur, to clean them up properly and either reuse or sell the oil. A procedure for handling oil and oil spills should be instituted and followed.

If the boiler is old, installation of a new boiler should be considered. Making the change from coal to oil, or from oil to natural gas, should also be considered. In some burners is it possible to install an oil atomiser and thereby increase efficiency. Both options (new boiler and atomiser) will often pay back the inestment within 5 years. The actual payback period depends on the efficiency of the existing boiler, the utilisation of the new boiler, the cost of fuel, and other factors.

Steam leaks should be repaired as soon as possible when identified. Even small steam leaks cause substantial losses of steam and corresponding losses of oil and money.

Insulation of hot surfaces is a cheap and very effective way of reducing energy consumption. The following equipment is often not insulated:

- valves, flanges;
- scalding vats/tanks;
- autoclaves;
- cooking vats;
- pipe connections to machinery.

Through proper insulation of this equipment, heat losses can be reduced by 90%. Often the payback period for insulation is less than 3 years.

If steam condensate from some areas is not returned to the boiler, both energy and water are wasted. Piping systems for returning condensate to the boiler should be installed to reduce energy losses. The payback period is short, because 1 m^3 of lost condensate represents 8.7 kg of oil at a condensate temperature of 100 C.

The efficiency of boilers depends on how they are operated. If the air to fuel ratio is wrongly adjusted incineration will be poor, causing more pollution and/or poorer utilisation of the fuel. Proper operation of the boiler requires proper training of employees and, if the expertise not is available within the company, frequent visits of specialists.

Case Study 3–11: Biogas production from fish waste

A New Zealand fish processor decided to look for an alternative to landfill for disposal of its fish wastes. After considerable research, the company installed a fish biodigester. Using anaerobic digestion, the plant now produces two useful by-products: methane and fertiliser. Methane (biogas) is used to heat the digester and to supplement the energy requirements of the plant. Sales of the by-products of what previously was waste are US$9000 per month. Energy savings amount to US$4000 per year and annual disposal charges of US$12,500 have been saved. The overall payback period is estimated at 6 years.

Case Study 3–12: Poorly operated coal-fired boiler

Samples of coal and waste ash were taken from coal-fired boilers and were measured for specific energy (kJ/kg), ash percentage and moisture percentage. Results showed that up to 29% of the total fuel supply was not being combusted in the boilers, with the least efficient boiler generating an additional 230 kg of unburnt material per tonne of coal. This unburnt material was retained in the ash and disposed of in landfill.

To improve performance, the company trained employees in efficient boiler operations, so that boilers could be run on automatic control. After this training boiler efficiency increased by 25%, and the specific energy fell to 6 kJ/kg.

Coal use has been reduced by 1500 tons, making an annual saving of US$45,000. Improved boiler operation has also reduced annual landfill disposal by 275 tonnes. The company has hired a specialist company to monitor boiler efficiency on an ongoing basis. The cost of this service is US$2100 per month.

3.5.3 Water supply

Process description

High-quality domestic water supplies may not need any treatment before use in the plant. However if the available water is of poor quality it may be necessary to treat it to meet hygiene requirements. Treatment normally consists of aeration and filtration through gravel or sand and chlorination may also be necessary.

Inputs and outputs

Figure 3–28 is a flow diagram showing the inputs and outputs from this process.

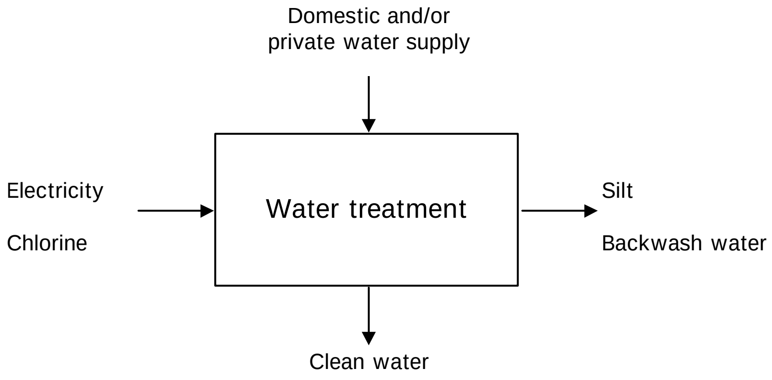

Figure 3–28 Inputs and outputs for water treatment

Environmental issues

Water is a valuable resource, so its use should be minimised wherever possible. Since electricity is needed for pumping water, energy consumption also increases with increasing water consumption.

The losses that occur due to holes in water pipes and running taps can be considerable. Table 3–40 shows the relationship between size of leaks and water loss.

Table 3–40 Water loss from leaks at 4.5 bar pressure [1]

Hole size (mm)	**Water loss** (m^3/day)	**Water loss** (m^3/year)
0.5	0.4	140
1	1.2	430
2	3.7	1300
4	18	6400
6	47	17,000

[1] UNEP, 1996.

Cleaner Production opportunities

To ensure that water consumption is optimised, consumption should be monitored on a regular basis. It is helpful to install water meters for separate departments and even for individual processes or pieces of equipment. Whether this is feasible depends on the level of water consumption and the expected savings in each instance. Water consumption can be reduced by 10–50% simply by increasing employees' awareness and by educating them on how to reduce unnecessary consumption.

Energy-efficient pumps should be installed to reduce the energy consumed for pumping of water. New and efficient pumps can reduce energy consumption by up to 50% compared with standard pumps. It is very important to select a pump with optimum pumping capacity and position it close to the required pump work.

3.5.4 Refrigeration and cooling

Process description

In refrigeration and cooling systems a refrigerant, typically ammonia or a chlorofluorocarbon (CFC)-based substance, is compressed, and its subsequent expansion is used to chill a closed circuit cooling system. The refrigerant itself can act as a primary coolant, recirculated directly through the cooling system, or alternatively, it can be used to chill a secondary coolant, typically brine or glycol.

CFCs were once extensively used in refrigeration systems, but they are now prohibited in most countries, and their use is being phased out as a result of the Montreal Protocol on ozone-depleting substances. All cooling systems should be closed circuit systems and free of leaks. However, due to wear and tear and inadequate maintenance, leaks may occur.

Inputs and outputs

Figure 3–29 is a flow diagram showing the inputs and outputs from this process.

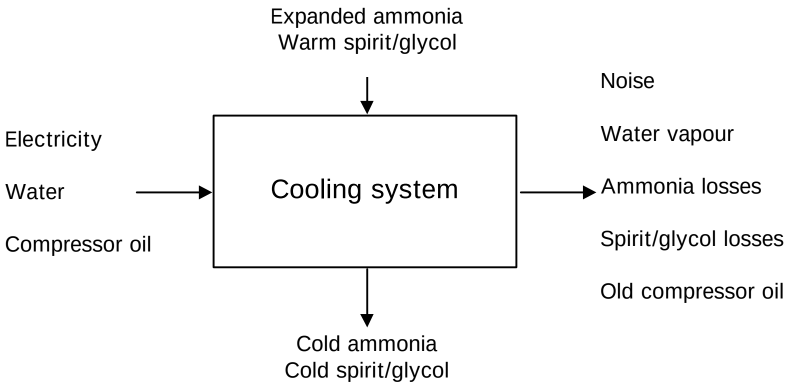

Figure 3–29 Inputs and outputs for cooling system

Environmental issues

The consumption of electricity and of water can be quite high.

If CFC-based refrigerants are used there is a risk that refrigerant gases will be emitted to the atmosphere, contributing to the depletion of the ozone layer. There is also a risk of ammonia and glycol leaks, which can be an occupational, health and safety problem for workers, but can also result in environmental problems.

Cleaner Production opportunities

CFC-based refrigerants should be replaced by the less hazardous hydrogenated chlorofluorocarbons (HCFCs) or, preferably, by ammonia. In the long run both CFCs and HCFCs should be replaced by other refrigerants according to the Montreal Protocol. Replacing CFCs can be expensive, as it may require the installation of new cooling equipment.

Minimising the ingress of heat into refrigerated areas can reduce energy consumption. This can be accomplished by insulating cold rooms and pipes that contain refrigerant, by closing doors and windows to cold areas, or by installing self-closing doors.

If water and electricity consumption in the cooling towers seems high, it could be due to algal growth on the evaporator pipes. Another reason could be that the fans are running at too high a speed, blowing the water off the cooling tower. Optimising the running of the cooling tower can save a lot of water.